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The Space Weather Forecast Testbed (SWFT) as a Community Resource to Advance Understanding of Space Weather Forecasts

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Heliospheric and ITM Community of Model Developers

Outline

1. Forecasting as a scientific frontier
2. The Space Weather Forecast Testbed
3. Forecasting global ionospheric indices
4. Summary

A Scientific Frontier

- **Forecasting conditions in the thermosphere-ionosphere (TI) with 1-4 day lead time using global 3D *first principles models***
  - **Forecast triggered by an Earthward directed CME or predicted arrival of a high speed stream and the stream interaction region**
- **Analogous to a "medium range" weather forecast**

Why is this a scientific frontier?

- **Global coupled TI models have been demonstrated – the "proof of concept" era has been successful**
- **Forecasts constitute the most rigorous tests of the models**
- **Through rigorous testing, the contributions of these models to scientific advancement will increase**

Relegating Forecasting to an Operational Activity is a Missed Opportunity

- **The "proof-of-concept" era has left many questions unanswered**
- **Model agreement with observations is only partial**
  - **We have had to assume that *agreement* implies sufficient physics, whereas *disagreement* implies poorly constrained drivers or inputs**
  - **How do we know this is in fact the case?**
- **Forecasting is an excellent research tool**
  - **Objective measures of model output reduces confirmation bias**
  - **All manner of events come under study, not just those where the models tend to be successful**

***Proposal:* that our community embrace forecasting using first-principles models as a research activity**

Space Weather Forecast Testbed

- **Our deliverable to CCMC for community use**
- **System for exploring forecasting scenarios using observations and first-principle model output**
- **Currently contains 10+ years of TEC maps, derived TEC properties, solar wind variables, solar proxies, geomagnetic indices, etc. at 3-hour cadence**
- **Data mining algorithm: multi-variable regression**
- **Rigorously separates training data sets from test data sets, and does so continuously in time, user selectable**
- **Helps the community understand the forecasting implications of our research and scientific understanding**

Multi-Linear Regression

- Regression consists of finding optimal coefficients for a linear model of the form:

$$v_X(t) = T\begin{pmatrix} \vec{u}(t-d) \\ \vdots \\ \vec{u}(t-d-m) \end{pmatrix}, \vec{u}(t) = \begin{pmatrix} v_X(t) \\ \vdots \\ B_X(t) \\ \vdots \\ n_{SunSPot}(t) \end{pmatrix}.$$

- Optimization for T consists of solving the least square minimization problem using historic data:

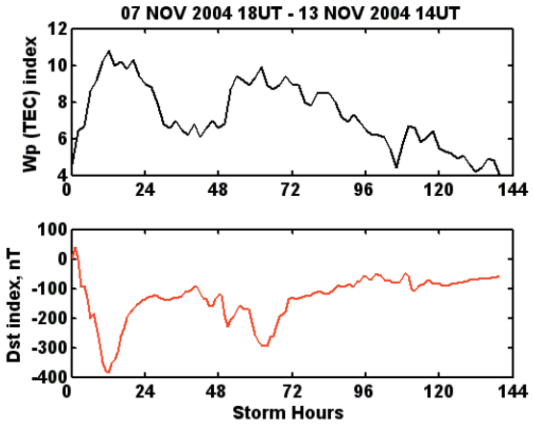
$$\min_T \sum_{k=1}^{N} \left| v_X(k) - T\begin{pmatrix} \vec{u}(k-d) \\ \vdots \\ \vec{u}(k-d-m) \end{pmatrix} \right|^2.$$

- "Fitting" step: generate regression coefficients and covariances
- "Forecast" step: evaluate the linear model using data not used in the fitting step

Convergence of Several Ideas

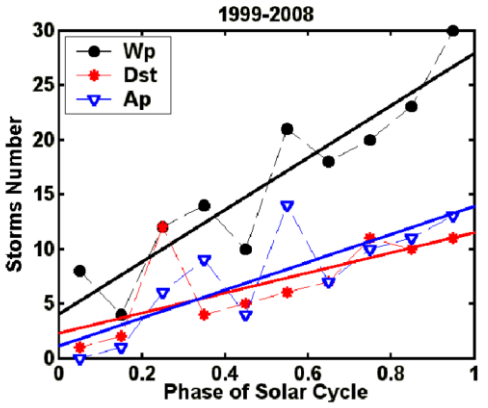
- **Development of an "ionospheric storm scale"**
  - **Analogous to Space Weather Prediction Center space weather scales for geomagnetic, solar radiation and radio blackout impacts**
- **Interest in forecasting ionospheric conditions with varying lead times from hours to days**
- **Proposal: forecast the ionospheric storm scale with varying lead times**

Time history of a global ionospheric versus geomagnetic storm index

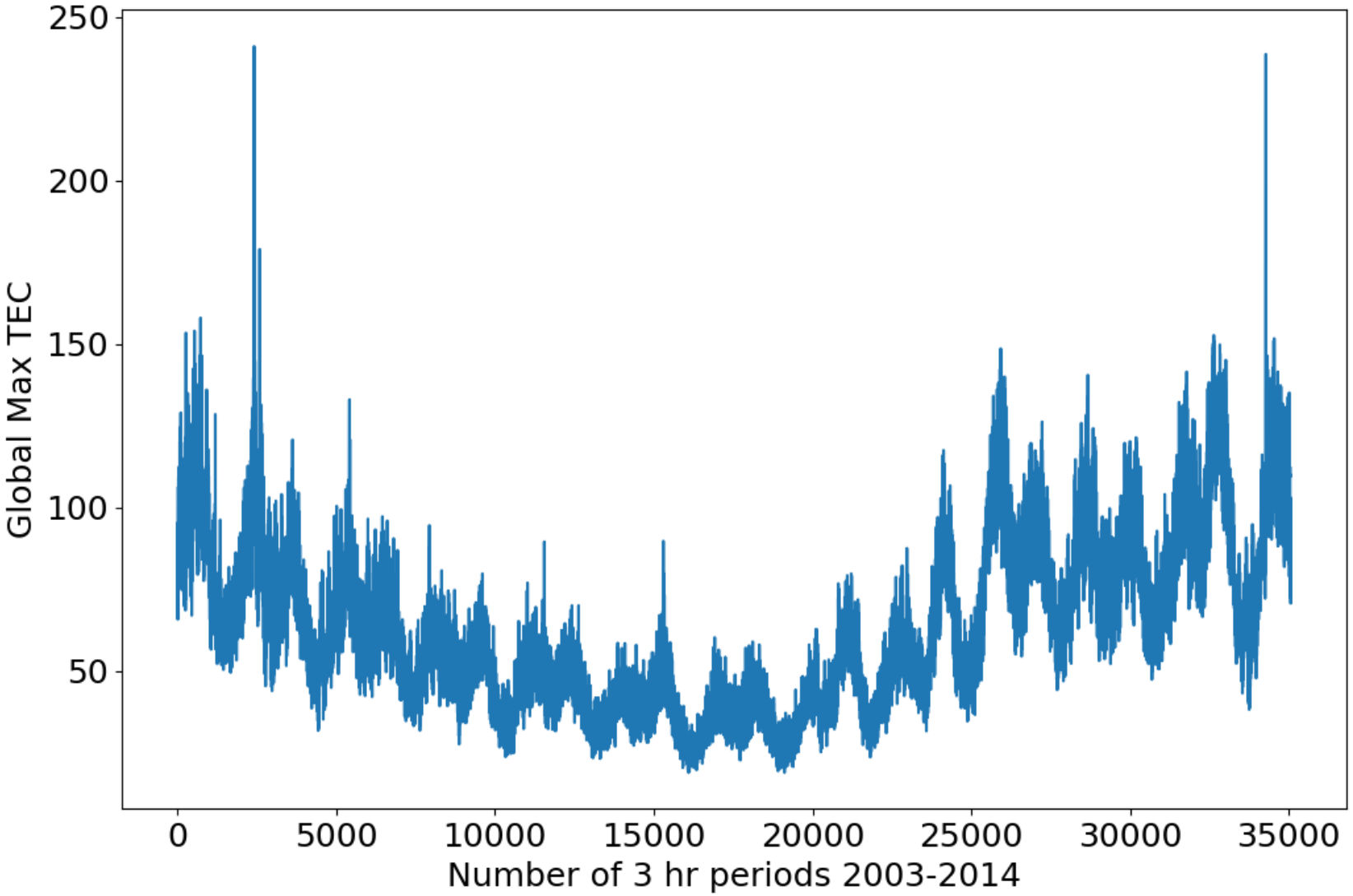


Gulyaeva, T. L., and I. Stanislawska (2008), Derivation of a planetary ionospheric storm index, *Annales Geophysicae*, *26*(9), 2645–2648, doi:10.5194/angeo-26-2645-2008.

Number of ionospheric versus geomagnetic storms above threshold

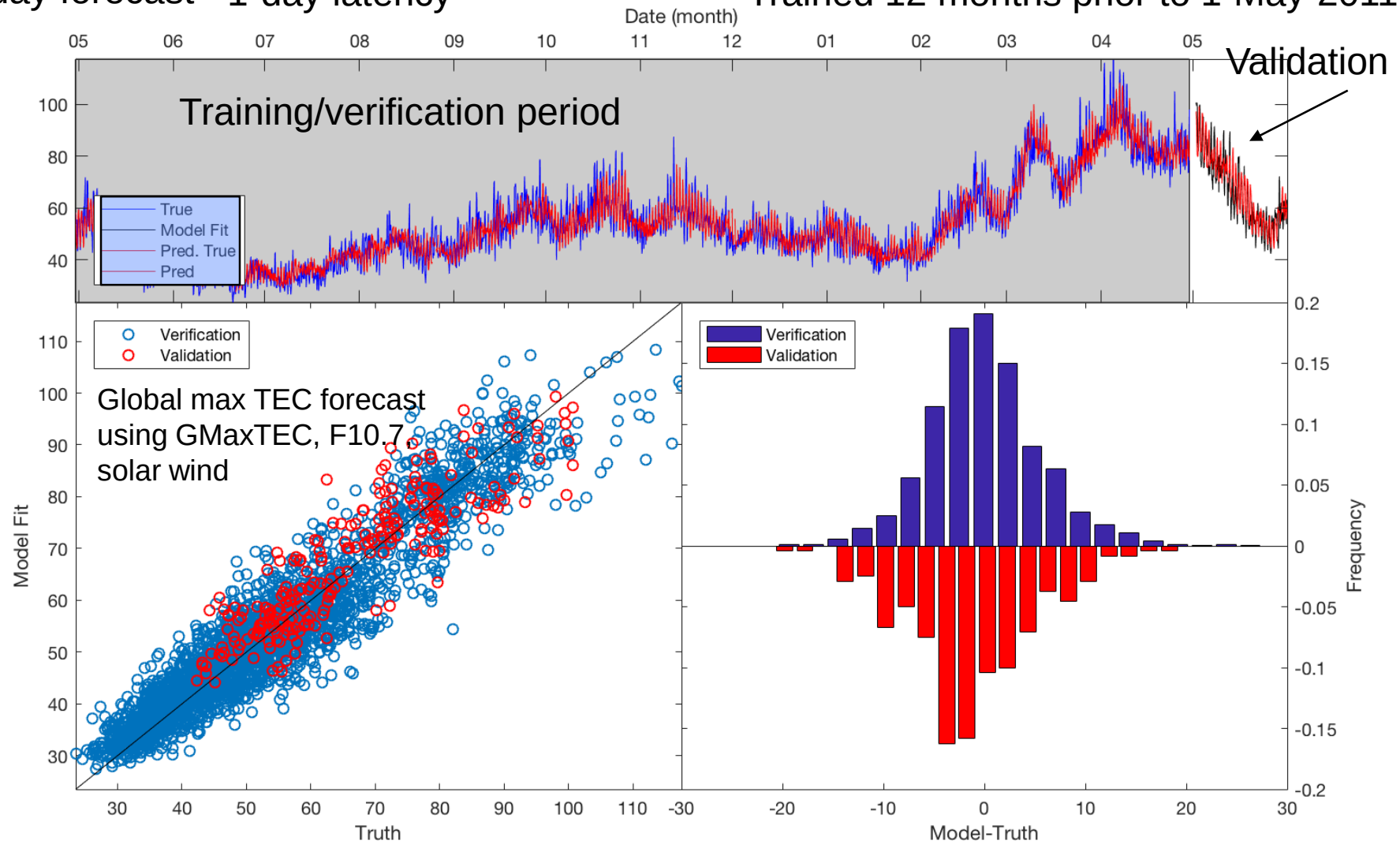


Global Maximum Ionospheric TEC



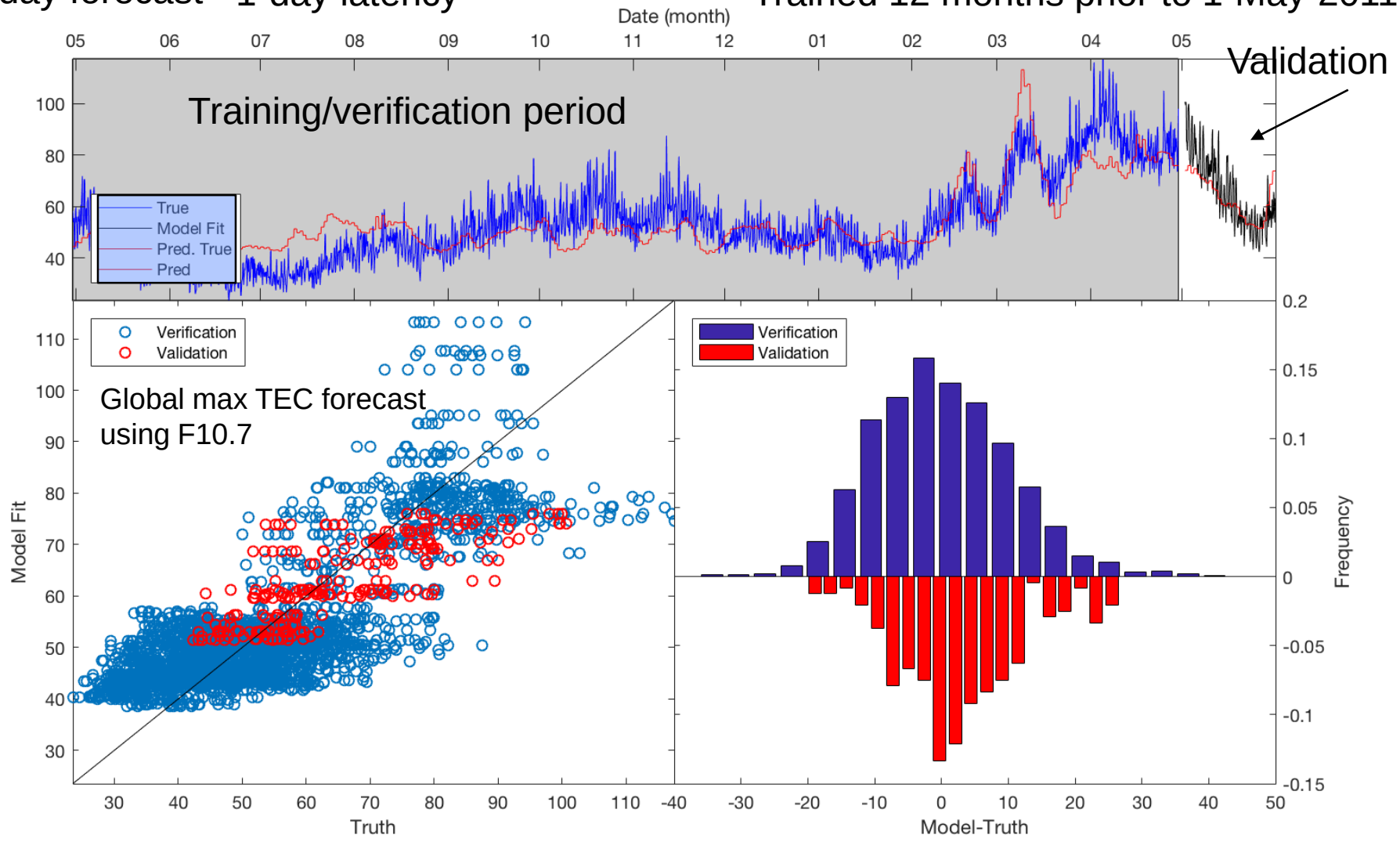
SWFT Output – Global Maximum TEC Forecast using GMaxTEC, F10.7, Solar Wind

1-day forecast 1-day latency Trained 12 months prior to 1-May-2011



SWFT Output – Global Maximum TEC Forecast using F10.7

1-day forecast 1-day latency Trained 12 months prior to 1-May-2011



SWFT Development

- **Planned for delivery to CCMC prior to May 2018**
- **Development will continue**
- **SWFT is currently a quiet time tool – dominated by quiet time training data**
- **We are generating first-principles "forecastable" model runs for input to SWFT (TIEGCM, CTIPe, GITM) to assess storm-time model forecasts**

Summary

Annual meeting theme: science serving society

- **Space weather forecasting is a scientific activity that will transform our field**
- **Forecasting using first principles-based models is the most rigourous test of our scientific understanding as represented by these models**
  - **Objective assessments of model output relative to observations**
  - **All events treated equally**
- **We are proposing forecasting as a *research activity***
  - **There is also an operational aspect**
- **Systems science approaches and machine-learning based discovery are needed**

BACKUP SLIDES